Photoionization of Singly-charged Noble Gas Ions

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INTRODUCTION

The description of electron correlation in open-shell atoms and ions remains a challenging problem in theoretical atomic physics. In the past, the halides served as test cases in the development of photoionization models for open-shell atoms. For instance, F[1,2], Cl[3] and Br[4], have each been the subject of numerous theoretical and experimental efforts. Recently, experimental studies involving singly-charged noble gas ions have become possible using the Ion-Photon Beamline (IPB) located on ALS beamline 10.0.1.2. This apparatus allows for experimental studies along isoelectronic sequences of atoms at unprecedented levels of detail and accuracy. These studies add a new dimension necessary to further refine models of atomic photoionization and improve the understanding of correlation-complex systems.

EXPERIMENT

Noble gas ion beams were produced in a hot-filament discharge source. The ions were accelerated to a kinetic energy of 6 keV. The resulting ion beams are mass analyzed with a 60º bending magnet. The ion beam is then merged onto the axis of the counter-propagating photon beam with a set of 90º spherical-sector bending-plates. The primary ion beam then enters a cylindrical interaction region which can be biased to energy-label the photoions. In the center of the interaction region, the spacial overlap between the photon- and ion-beams is measured using a stepping motor driven slit scanner. Similarly, rotating-wire beam profile monitors are also used at the beginning and end of the interaction region in order to ensure that the beams are well collimated along the entire interaction region. Fine-tuning of the beams overlap was achieved with two sets of mutually perpendicular electrostatic steering plates mounted immediately before the merging bend plates. The photon intensity was monitored using a Si p-n junction photodiode. A second 45º analyzing magnet was used to disperse doubly-charged photoions produced in the interaction region from singly-charged ions in the primary beam. Following dispersion into the vertical plane, the primary beam is collected in a Faraday cup, while the photoions pass through a hole in the back of the cup. The primary ion beam current is monitored for normalization of the photo-ion yield. After the photoion beam has passed through the Faraday cup, it enters another set of 90º spherical-sector bending-plates. Thereafter, the photoions enter a negatively-biased detection box, wherein, the ions impinge upon a stainless steel plate and produce secondary electrons. The secondary electrons are in turn accelerated towards a Microspherical Plate (MSP) detector with a positively-biased anode. It should be noted that doubly-charged ions are also produced in collisions between the fast-moving ions in the primary beam and residual gas molecules in the vacuum system. Hence, it is necessary to modulate the photon beam in order to subtract background counts not associated with the photoionization process.

RESULTS

Shown in Figure 1 below is an energy spectrum for the photoionization of Ar^+ (Cl-like) from below the $^2P_{1/2}{}^o$ metastable state threshold (27.452eV) to the $3s^23p^4$ ($^1S_0{}^e$)ns,nd Rydberg series limit (31.754eV). Also visible in the spectrum are resonances of the $3s^23p^4(^1D_2{}^e)$ns,nd Rydberg series converging to a series limit of 29.367eV. These spectra were taken with a nominal photon energy resolution of 15meV using an energy step size of 2meV. The photon energy scale was calibrated using measurements of the $O^+(^4S)$ ground-state energy thresholds. The absolute uncertainty in the energy scale is ±2meV.

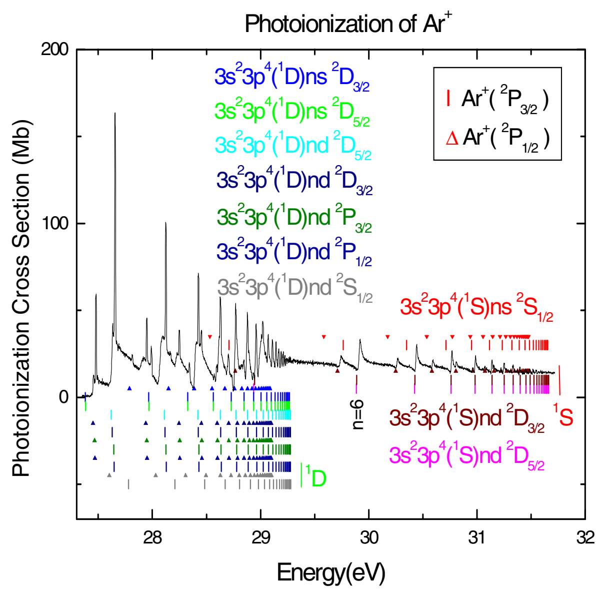

Figure 1

Absolute measurements of photoionization cross sections were made at discrete photon energies across the range of spectroscopic data. At each discrete photon energy ($h\nu$), the value of the total absolute photoionization cross section σ_{pi} can be determined using the following relation,

$$\sigma_{pi}(h\nu) = \frac{Rqe^2 \mathrm{v}_i}{I^+ I^\gamma \int \mathrm{F} \cdot \mathrm{dl}} \cdot \frac{\varepsilon}{\delta} \cdot \frac{1}{\Delta} \cdot \frac{1}{\Omega}. \qquad 1)$$

In Eq. 1) above, R is the photoion count rate (s^{-1}), q is the charge state of the target ion, e = 1.6×10^{-19}C, v_i is the ion velocity, I^+ is the ion beam current, I^γ is the photodiode current, ε is the responsivity of the photodiode, δ is the pulse transmission constant for the charged-particle detection system, Δ is the ion detection efficiency, Ω is the photoion collection efficiency, and the integral gives the overlap between the photon and ion beams along the length of interaction.

Shown in Figure 2 are the results of absolute measurements of Ar^+ along with error bars at one standard deviation of the mean. Also shown are spectroscopic data normalized to the absolute points along with the results of a recent 26-state R-matrix calculation[5] (dashed-line).

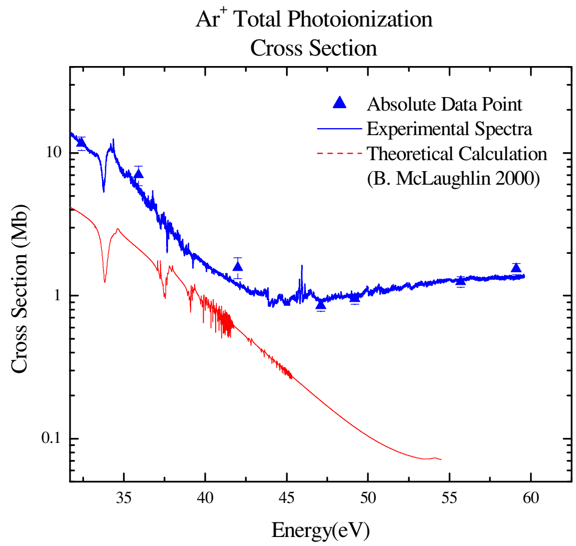

Figure 2

The difference between theory and experiment ranges from a factor of 5 at (32 eV) to a factor of ~20 at (55 eV). The source of difference and divergence between theory and experiment has yet to be resolved. One possibility is that photoionization channels involving multi-electron excitations not included in the calculation are opening at higher photon energies. Measurements have also been carried out with Ne^+(F-like) and Kr^+ (Br-like) ions.

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